SILVER INCORPORATED ALUM TREATED BITUMINOUS COAL MEDIA FOR REMOVAL OF BACTERIA AND TURBIDITY FROM WATER

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to the

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APRIL, 1988

To my daughter

Risha

CERTIFICATE

Certified that the work presented in this thesis entitled 'Silver Incorporated Alum Treated Bituminous Coal Media for Removal of Bacteria and Turbidity from Water' by Md. Showkat Osman has been carried out under my supervision and has not been submitted elsewhere for a degree.

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ABSTRACT

The present study was undertaken to standardise the method of preparation of silver incorporated alum treated bituminous coal media and to further test its performance in removing bacteria and turbidity from water, using column studies. Standardisation of the procedure for alum treatment of bituminous coal in terms of concentration of alum solution and time of agitation was carried out by batch sorption tests; 0.075 M alum solution and 6 h agitation time was selected for alum treatment. Silver was incorporated employing two methods, viz., silver incorporation following alum treatment and silver incorporation along with alum treatment. Six h contact time was found optimum for silver incorporation, using a 0.5 mg Ag/L silver solution. Effectiveness of the prepared media, viz., Alum-GBC-Ag (silver incorporation following alum treatment) and Alum/Ag-GBC (silver incorporation along with alum treatment) in removing bacteria and turbidity from water was investigated in column studies, employing the Ganga water. Alum-GBC-Ag exhibited better performance than Alum/Ag-GBC and also showed improved performance in comparison to the media prepared by Jayadev (1987). High removal of total coliform (90 percent) and heterotrophic plate count bacteria (88 percent) were observed in Alum-GBC-Ag – well water column study. Effluent characteristics (faecal coliforms 0-3/ 100 mL, heterotrophic plate count bacteria 7-44 CFU/mL and

turbidity 1.2-3.0 NTU) of long duration column studies (4-8 d), employing the Ganga water (faecal coliforms 14-130/100 mL heterotrophic plate count bacteria 60-190 CFU/mL and turbidity 12.0-23.5 NTU), demonstrated the potential of Alum-GBC-Ag as a media for domestic water filters in the rural areas of the developing countries. Standardisation of the method of media preparation carried out in the present study is a significant advancement in the direction of development of filtration/ adsorption media for removal of bacteria and turbidity from water.

1. INTRODUCTION

Because of the essential role played by water in supporting human life, it also has, if contaminated, a great potential for transmitting a wide variety of diseases. In the developed world, water-related diseases are rare, due essentially to the presence of efficient water supply systems. However, in the developing world perhaps as many as 2000 million people are without safe water supply. As a result, the toll of water-related disease in these areas is quite frightening. It is, therefore, important for the environmental engineers to take the challenge of supplying water, adequate in quantity and safe in quality, which is essential for the very existence of human life.

According to a review by the World Health Organisation of national baseline data reported by 86 developing countries/territories for the end of 1980, three urban residents out of four had access to safe drinking water (WHO, 1984a). In India, at the end of 1980, 59 percent of the population (23 percent urban and 69 percent rural) did not have access to safe drinking water. In the developing countries, about 80 percent of all sickness and diseases can be attributed to inadequate quality of water and sanitation; diarrheal diseases kill 6 million children every year and contribute to the death of upto 18 million people whereas more than 400 million people have gastroenteritis (Lee, 1984).

The United Nations Conference on Human Settlement (HABITAT) held in 1976 emphasised the theme 'Clean water and sanitation

for all by 1990' which was picked up by the U.N. Water Conference held at Mar del Plata, Argentina in March, 1977. In this conference, it was considered that all people, irrespective of their stage of development and their social and economic conditions, had the right of access to good quality drinking water, in quantities equal to their basic needs. The conference designated the eighties as the "International Drinking Water Supply and Sanitation Decade." The Government of India being one of the participants to this conference also pledged to provide safe water to 100 percent of its urban and rural population by 1990 (Dhage *et al.*, 1986).

In India, the reported incidence of water-borne diseases is 800 cases per 100,000 annually (WHO, 1984a) and more than two million deaths occur yearly due to water-borne diseases and over 50 million persons are partially incapacitated annually by these ailments (Kulkàrni *et al.*, 1980). According to a report of the Indian Planning Commission (Govt. of India, 1981), water-borne or water-related diseases constitute nearly 80 percent of the country's public health problem.

A national water supply program was launched in 1954 during the First Five Year Plan and progressively larger allocations were made for water supply and sanitation in the succeeding Five Year Plans; but the available statistics relating to the status of rural and urban water supply present a discouraging picture, especially in the rural areas (Govt. of India, 1981). The rural population of India is about 80 percent of the total population. For this large rural communities, providing safe

and adequate drinking water is an extremely challenging task, though top priority is being given to rural water supply schemes. As of March, 1980, about 200,000 villages with a total population of 160 million were yet to be provided with potable water supply facilities (Govt. of India, 1981). The situation in the urban areas was relatively better; but in the hundreds of smaller towns, the water supply arrangements were far from adequate. The importance of providing safe water supply as a basic minimum need was reiterated in the Draft Fifth Five Year Plan (1974-79) which included drinking water for villages in its Minimum Needs Program. A mid-term appraisal of the Sixth Five Year Plan revealed that financial constraints were foremost in view of the overall resource scarcity and the need for cheaper systems became more apparent (Govt. of India, 1983). In the Seventh Five Year Plan (1985-1990), every effort is being made to provide adequate and safe drinking water facilities to 100 percent of the population in keeping with the objectives of the International Drinking Water Supply and Sanitation Decade (Govt. of India, 1984). According to a 1984 estimate, the estimated cost to reach the country's Decade target was U.S. $17,708 million (WHO, 1984a). According to a recent newspaper report (The Statesman, 1988), during the first phase (1981-85) of the Decade the investment in urban water supply was of the order of Rs. 910 crores and 73 percent of the urban population was covered by safe water supply. With more investment in recent years, it rose to 76 percent.

Due to the limited financial resources, supply of drinking water in sufficient quantity and of acceptable quality to the

growing population in the developing countries has been a challenging problem. For the poor economic condition of the developing countries, it is not advisable to rely on sophisticated technology which is appropriate for a developed country. Instead, developing indigenous technology which is economically viable, scientifically sound, technologically feasible and socially acceptable can be the greatest measure of economy for India as well as other developing countries. A logical approach in this direction would be development of filtration/adsorption media using indigenous material which can be ultimately incorporated into small-scale or domestic water filters.

Laboratory studies at the Indian Institute of Technology, Kanpur during the past decade showed the potential of raw bituminous coal in removing model viruses from water (Oza and Chaudhuri, 1975; Sriramulu and Chaudhuri, 1976; Oza and Chaudhuri, 1976; Oza and Chaudhuri, 1977), hydrous iron/manganese oxides impregnated bituminous coal in removing organics (humic acid) (Jayasimha, 1983) and raw as well as chemically pretreated bituminous coal in removing heavy metals (mercury and cadmium) from water (Pandey and Chaudhuri, 1981; Pandey and Chaudhuri, 1982; Kartikeyan, 1982; Bhattacharya and Venkobachar, 1984; Kiran Kumar, 1984). In a recent study (Prasad, 1986) on development of filtration/adsorption media, using indigenous low-cost materials, for removal of bacteria and turbidity from water, alum treated Giridih bituminous coal ranked highest among the bituminous coal-based media. Alum treated Giridih bituminous coal was also found effective in removing enteric viruses

(polio and rota) from water (Chaudhuri and Sattar, 1986 and 1988). Following up on the work of Prasad (1986), Jayadev (1987) demonstrated the usefulness of incorporating silver into alum treated Giridih bituminous coal in improving its performance.

The objective of the present study was to standardise the preparation of silver incorporated alum treated bituminous coal and further demonstrate its effectiveness in removing bacteria and turbidity from water in column studies employing surface as well as ground water samples.

2. BACKGROUND INFORMATION

This chapter presents information to provide a background for the study - water quality with a brief discussion on the microbiological water quality for small-scale water supplies in the developing countries, studies on removal of viruses and bacteria from water by coal/coal-based and other filtration/adsorption media, microbiological effectiveness of silver and its use in water filters, limits of silver in water and its effects on human beings, previous work on silver incorporated coal-based filtration/adsorption media. A brief section on point of use water filter is also included.

2.1 Drinking Water Quality

Drinking water, either directly or indirectly contaminated by sewage, human and animal excrement or other wastes, is the most common and widespread danger for diseases. If such contamination is recent, and if among the contributors there are carriers of communicable enteric diseases, some of the living causal agents may be present. Using water of such contamination for drinking purpose or for the preparation of certain foods may result in further cases of infection. Faecal pollution of drinking water may introduce a variety of intestinal pathogens-bacterial, viral and parasitic - their presence being related to microbial diseases and carriers, present at that moment in the community (WHO, 1984c).

2.1.1 Waterborne Bacterial Pathogens

Intestinal bacterial pathogens are widely distributed throughout the world. Those known to have occurred in contaminated drinking water include strains of *Salmonella typhi*, *Shigella flexneri*, exterotoxigenic *Escherichia coli*, *Vibrio cholerae*, *Yersinia exterocalitica* and *Campylobacter fetus*. These organisms may cause diseases that vary in severity from mild gastroenteritis to severe and sometimes fatal dysentry, cholera, or typhoid.

Among the various waterborne pathogens, there exists a wide range of minimum infectious dose levels necessary to cause a human infection. Ingestion of relatively few organisms of *Salmonella typhi* can cause disease. With *Shigella flexneri*, several hundred cells may be needed, whereas many millions of cells of *Salmonella* serotypes are usually required to cause gastroenteritis. Similarly, with toxigenic organisms such as exteropathogenic *Escherichia coli* and *Vibrio cholerae*, as many as 10^8 organisms may be necessary to cause illness. The size of the infective dose also varies in different persons with age, nutritional status, and general health at the time of exposure.

2.1.2 Indicator of Faecal Pollution

Although it is possible to detect the presence of many pathogens in water, the methods of isolation and enumeration are often complex and time consuming. Therefore, it is impracticable to monitor drinking water for every possible microbial pathogen that might occur with contamination. A more

logical approach is the detection of organisms normally present in the faeces of man and other warm blooded animals as indicators of excremental pollution, as well as of the efficacy of the water treatment. Presence of such organisms indicates the presence of faecal material, and that intestinal pathogens could be present. Conversely, the absence of faecal commensal organisms indicates that pathogens are probably absent. Indicator organisms should be abundant in excrement but absent, or present only in small numbers, in other sources. They should be easily isolated, identified and enumerated and should be unable to grow in water. They should also survive longer than pathogens in water and be more resistant to disinfectants. In practice, these criteria cannot all be met by any one organism, although many of them are fulfilled by the coliform organisms, especially <u>Escherichia coli</u> as the essential indicator of pollution by faecal material of human or animal origin. Other microorganisms that satisfy some of these criteria, though not to the same extent as coliform organisms, can also be used as supplementary indicators of faecal pollution in certain circumstances. Organisms used as bacterial indicators of faecal pollution include the coliform group of organisms as a whole, <u>Escherichia coli</u> and coliform organisms that have been described as faecal coliforms , faecal streptococci, and sulfite-reducing clostridia, especially <u>Clostridium perfringens</u>. Complete identification of <u>Escherichia coli</u> in terms of modern taxonomy would require an extensive series of tests, which would be impracticable for routine water examination. Therefore,

detection and identification of these organisms as faecal organisms or presumptive Escherichia coli is considered to provide sufficient information to assess the faecal nature of pollution.

The occurrence of faecal streptococci in water generally indicates faecal pollution. However, this indicator group has rarely been recommended for control of drinking water quality because of their persistence in water with moderate salt concentration (Geldreich, 1976).

Clostridium perfringes of the sulfite-reducing clostridia group is normally present in faeces though in much smaller numbers than Escherichia coli. However, it is not considered for routine monitoring, since they tend to survive and accumulate for a longer time. They may thus be detected remote in both time and place from the original source of pollution and consequently give rise to false alarms. Table 1 shows the guideline values for bacteriological quality of drinking water recommended by WHO (WHO, 1984b).

2.1.3 Turbidity

Turbidity in water is caused by the presence of suspended matter, such as clay, silt, colloidal organic particles, plankton, and other microscopic organisms. The particles that cause turbidity in water range in size from colloidal dimensions (10 nm) to diameters of the order of 0.1 mm. Presence of turbidity can have a significant effect on the microbiological quality of drinking water as detection of bacteria and viruses in drinking water may be complicated by

Table 1. Guideline Values for Bacteriological Quality

Organism	Unit	Guideline value	Remarks
A. <u>Piped water supplies</u>			
A.1 <u>Treated water entering the distribution system</u>			
faecal coliforms	number/100 ml	0	turbidity < 1 NTU; for disinfection with chlorine, pH preferably < 8.0, free chlorine residual 0.2-0.5 mg/Li following 30 min (minimum) contact
coliform organisms	number/100 ml	0	
A.2 <u>Untreated water entering the distribution system</u>			
faecal coliforms	number/100 ml	0	in 98% of samples examined throughout the year - in the case of large supplies when sufficient samples are examined
coliform organisms	number/100 ml	0	
coliform organisms	number/100 ml	3	in an occasional sample, but not in consecutive samples
A.3 <u>Water in the distribution system</u>			
faecal coliforms	number/100 ml	0	
coliform organisms	number/100 ml	0	in 95% of samples examined throughout the year - in the case of large supplies when sufficient samples are examined
coliform organisms	number/100 ml	3	in an occasional sample but not in consecutive samples
B. <u>Unpiped water supplies</u>			
faecal coliforms	number/100 ml	0	
coliform organisms	number/100 ml	10	should not occur repeatedly; if occurrence is frequent and if sanitary protection cannot be improved an alternative source must be found if possible
C. <u>Bottled drinking water</u>			
faecal coliforms	number/100 ml	0	source should be free from faecal contamination
coliform organisms	number/100 ml	0	
D. <u>Emergency water supplies</u>			
faecal coliforms	number/100 ml	0	advise public to boil water in case of failure to meet guideline values
coliform organisms	number/100 ml	0	

the presence of turbidity. Further in water microbial growth is most extensive on the surfaces of particles and inside loose, naturally occurring floc. The growth is facilitated because nutrients are adsorbed onto surfaces and the attached bacteria are thus able to grow more efficiently compared to discrete organisms. The adsorptive capacity of suspended particulates can lead to entrapment of undesirable inorganic and organic compounds present in the water and in this way, turbidity can bear an indirect relationship to the health aspects of water quality. The guideline value for turbidity in drinking water (WHO, 1984b) is 5 Nephelometric Turbidity Units (NTU) or 5 Jackson Turbidity Units (JTU) but preferably less than 1 NTU when disinfection is practised.

2.1.4 Microbiological Water Quality for Small-Scale Water Supplies in the Developing Countries

It has been emphasised that the levels recommended in the guidelines for drinking water quality (WHO, 1984b) are not standard in themselves. In order to define standards, it is necessary to consider these recommendations in the context of prevailing environmental, social, economic, and cultural conditions. It is to be expected that the adoption of standards will be influenced by national priorities and economic factors; however, considerations of policy and convenience must never be allowed to endanger public health (WHO, 1984b).

Feachem (1980) is of the opinion that it is pointless to insist that all water supplies contain no faecal coliforms. In cases where all the population drink treated piped water, it is reasonable and correct to stipulate that no coliforms or

other indicator bacteria should be detectable in tap water. Failure to meet this standard indicates a malfunction of the treatment plant, especially the chlorination unit or pollution via a damaged section of the distribution system. However, where most of the population drink from improved but untreated supplies, even if great attention is paid to selecting the purest available water source and distributing the water through a well designed and maintained system, it will not usually be possible to meet a zero faecal coliform standard without chlorination. Accordingly, a preferable approach to a zero faecal coliform standard is to set flexible quality goals which can be changed as progress is achieved. As there is a minimum infectious dose for all pathogens, it may not always be required to achieve 'zero faecal coliforms.' It is not the intention here to advocate a relaxation of bacterial quality for drinking water. Any device which can reduce substantial number of coliforms from drinking water will be a step in the direction of achieving the ultimate goal of 'no faecal coliform' in the drinking water. In small-scale water treatment, particularly household devices, it may be more usual for water quality to deteriorate between collection and use because either the water collection vessels are contaminated or the water is stored in such a way that it can be further contaminated. Educating the users also is very important when such devices are recommended for household use.

2.2 Coal/Coal-Based and Other Filtration/Adsorption Media

Usefulness of bituminous coal, raw as well as treated/ impregnated with various chemicals, in removing viruses and bacteria from water was explored in a number of studies at the Indian Institute of Technology, Kanpur and the University of Ottawa, Canada.

Giridih bituminous coal was found to be effective in removing model bacterial viruses from water (Oza and Chaudhuri, 1975; Sriramulu and Chaudhuri, 1976; Oza and Chaudhuri, 1976 and 1977). Alum treated Giridih bituminous coal was also found effective in removing enteric viruses (polio and rota) from water (Chaudhuri and Sattar, 1986 and 1988).

Prasad (1986) undertook a study to develop filtration/ adsorption media, using indigenous low-cost materials like lignite, bituminous coal, iron ore, manganese ore and crushed coconut shell, for removal of bacteria and turbidity from water. He studied the performance of these media, both raw as well as treated/impregnated with various chemicals (alum, ferric chloride, lime, δ-MnO_2, hydrochloric acid). In all, he studied thirty three media out of which three, viz., ferric hydroxide impregnated lignite, lime coated manganese ore and alum treated manganese ore were capable of effectively removing bacteria from water both in presence as well as absence of turbidity; however, alum treated Giridih bituminous coal ranked highest among the bituminous coal-based media. These three media showed high <u>Escherichia</u> <u>coli</u> removal (almost 100 percent) in column studies and were able to produce a filtered water with

turbidity equal to or below 5 NTU. He observed that a significant fraction of the sorbed bacteria (70 to 96 percent) remained viable and could be eluted in desorption test. He also observed growth of bacteria on the media surface. To overcome this problem and for possible improvement in performance, he suggested use of a bactericidal chemical during treatment/impregnation.

2.3 Microbicidal Effectiveness of Silver and Its Use in Water Filters

Germicidal effect of silver and its 'oligodynamic' action has been known for about 100 years. The term 'oligodynamic' means 'effect or power in small amounts' (Smith _et al_., 1977). Richard (1963) quoted in his review that most studies of bactericidal effectiveness of silver used the common indicator organism, _Escherichia coli_, as test organism. Wuhrmann and Zobrist (Richard, 1963) studied a few other organisms and reviewed other work on this subject. They concluded that _Salmonella_ was at least as sensitive to silver as _Escherichia coli_ but suggested the need for further research on a number of organisms. Cysts of _Endameba histolytica_ and bacterial spores are much more resistant to silver than vegetative bacteria. Very little is known about the effect of silver on viruses. Recently, Mahnel and Schmidt (1986) studied the effect of some silver compounds on viruses in water and reported increased lability of the viruses (ECBO, influenza A, Newcastle disease, pseudorabies and vaccinia viruses).

As reported by Wuhrmann and Zobrist (Richard, 1963), silver inactivation followed a first order reaction and that temperature, pH, concentration of silver and time of contact affected

the results. A rise of temperature by 10°C decreased the kill time by a factor of 1.6, and increasing the pH by one unit also decreased the kill time by a factor of about 1.6. These results may be compared with the results of Chambers and Proctor (Richard, 1963). They were either in reasonably good agreement or show somewhat faster kills. On the other hand, Renn and Chesney's (Richard, 1963) results showed generally faster kills and, in general, their kill curves did not follow first order reaction. Renn and Chesney observed quite large reductions in bacteria upon passage through a silver-coated activated carbon contact bed. The reductions on passage through a comparable activated carbon bed without silver were very small.

There are numerous water treatment devices incorporating silver as an antimicrobial agent. Most of these units which disinfect water with silver, use a filtration step designed to filter out bacteria. In the case of the Sterasyl and Katadyn products, a ceramic filter candle is used, and in case of the Filopur/Ogden and Sysc-Ro units, a membrane is used for filtration (Smith et al., 1977).

2.4 Limits of Silver in Water and Its Effects on Human Beings

Levels of silver in natural waters are very low. There is insufficient information to provide precise levels in water, but some data suggest that few water sources contain more than 1 μg/l of silver and levels greater than 10 μg/l are rare (WHO, 1984c). A number of conventional water treatment practices have been shown to be effective in removing silver from water and, consequently, many treated waters

contain very low levels of silver. However, because some metals (such as lead and zinc) used in distribution system may contain traces of silver, and also because in some countries silver oxide is used to disinfect water supplies, silver levels in tap water may sometimes be elevated. As quoted in WHO Guidelines for Drinking Water Quality (WHO, 1984c), levels exceeding 50 μg/l have been recorded on rare occasions, particularly when point-of-use water purifiers containing silver have been employed to obtain drinking water.

Relatively little is known about the absorption and metabolism of silver in man (WHO, 1984c). Most of the absorbed silver is excreted almost exclusively with the faeces. Silver that is available for excretion has a biological lifetime in the body ranging from a few days to a few weeks. With extremely high doses of silver, cases of fatal poisoning have been recorded. However, the main effect is discoloration of skin, hair, and fingernails which is called argyria. Pathological changes have been observed in the kidneys and liver of rats consuming water with silver concentrations of 400 μg/l and above. It is difficult, however, to extrapolate these results to man. If it is assumed that the first appearance of argyria has no significant health effect, then the discoloration could be used to estimate a safe exposure level. The minimum dose for human beings that might induce argyria is 1000 mg silver. A lifetime (70 years) exposure to 1000 mg of silver would be equivalent to a continuous daily exposure to 40 μg of silver.

However, because silver is continuously excreted and only approximately 10 percent is absorbed, the daily exposure level needed to cause argyria over a lifetime could be as high as 400 μg.

2.5 Silver Incorporated Coal-Based Filtration/Adsorption Media

Following up on the work of Prasad (1986), Jayadev (1987) demonstrated the usefulness of incorporating silver as a bactericide into ferric hydroxide impregnated lignite and alum treated Giridih bituminous coal in improving their performance in removing bacteria from water. He incorporated silver into both raw as well as treated/impregnated coal and lignite and investigated the effectiveness of silver incorporation using batch sorption and desorption tests as well as column studies, employing filter-sterilized Lower Ganga Canal water, spiked with laboratory grown *Escherichia coli* as well as canal water with its natural bacterial population and turbidity. In terms of *Escherichia coli* sorption capacity, silver incorporated alum treated Giridih bituminous coal ranked highest. In desorption test, silver incorporated media had low number of viable *Escherichia coli* in eluate which further decreased with increase in contact time, indicating *in situ* or contact inactivation of the sorbed bacteria. Silver incorporated alum treated Giridih bituminous coal performed best in the column study with high bacterial removal (96 percent total coliform and 82 percent total plate count bacteria).

2.6 Point-of-Use Water Filters

Point-of-use water filters will be useful where piped water supply is not available. They can also supplement centralised water treatment or remove the chance of contamination in the distribution system from the water supplied through household taps.

Kulkarni et al. (1980) evaluated the performance of candle filters and small filters attachable to tap that are available in India. They performed tests using water of turbidity 30 NTU and bacterial concentration 9200/100 mL, and found that the small filters attachable to tap did not remove even turbidity to a satisfactory level. Hence, the reliability of these small filters attachable to tap in producing bacteriologically safe drinking water was questionable. However, candle filters were satisfactory so far as the turbidity removal was concerned but the bacteriological quality of the filtered water was considerably unsatisfactory. Recently, Ion Exchange (India) Ltd. has marketed a Zero-B tap attachment for candle filter which is claimed to produce zero-bacteria water. However, no performance data are available.

A 'pocket purifier' for personal filtering of water from any source was developed by a manufacturer in the United States (Water Front, 1982). It is basically a pen-sized drinking straw containing particle removal filters, resin media to trap microorganisms, and activated carbon to remove impurities and make the water palatable.

3. SCOPE OF THE STUDY

The study of Jayadev (1987) on removal of bacteria and turbidity from water by silver incorporated alum treated Giridih bituminous coal suggested potential usefulness of such media for domestic water filters. The present study was undertaken as a follow-up of Jayadev's work to standardise the preparation of silver incorporated alum treated bituminous coal media and to further test its performance using column studies. The study was carried out along the following lines:

a. to standardise the procedure for alum treatment of bituminous coal in terms of concentration of the alum solution and time of agitation, using batch sorption tests,

b. to compare two methods of silver incorporation, viz., silver incorporation following alum treatment and silver incorporation along with alum treatment, and to estimate the time for silver incorporation, and

c. to test the performance of the prepared media in removing bacteria and turbidity from water in column studies, employing surface as well as ground water samples.

4. MATERIALS AND METHODS

4.1 Materials

4.1.1 Bituminous Coal

Bituminous coal from Giridih, Bihar, supplied by the National Environmental Engineering Research Institute, Nagpur, was used. The coal was crushed to a geometric mean size of 0.387 mm, washed several times with distilled water to remove the fines and other adhered impurities, dried overnight at 103°C and used for media preparation.

4.1.2 Water

Water samples from the Ganga river and a dug-well, located near the main gate of the I.I.T.,Kanpur campus, were used in the column studies. Typical characteristics of the two water samples are shown in Table 2.

4.2 Methods

4.2.1 Alum Treatment of Bituminous Coal

Batch sorption tests were employed to standardise the procedure for alum treatment of bituminous coal in terms of concentration of alum solution and time of agitation. Sorption kinetic tests, using three alum ($Al_2(SO_4)_3$, $16H_2O$) concentrations (0.025, 0.050 and 0.075 M), were performed to estimate the optimum time of agitation for alum treatment. In the procedure, Giridih bituminous coal (5 percent) in 100 ml alum solution in 300 ml glass stoppered bottles were agitated at the rate of 20 rpm in an end-over-end shaker. At the end of the desired contact times, the coal was allowed to settle for one min and

Table 2. Characteristics of Water Samples

Parameter	Ganga water	Well water
pH	7.9 - 8.5	8.0 - 8.4
Turbidity, NTU	12 - 24	8 - 10
Conductivity, μmhos/cm at 24°C	300	700
Faecal coliforms/100 mL[a]	70 - 130	Not detected
Total coliform, CFU/mL[b]	56 - 100	48 - 66
Heterotrophic plate count, CFU/mL[c]	130 - 190	86 - 110

[a]Membrane Filter (MF) Method - 44 ± 0.5°C/24 h - MFC broth (WHO, 1985).

[b]Pour Plate Method - 37 ± 0.5°C/48 ± 3 h - MacConkey agar (McCambridge and McMeekin, 1979)

[c]Pour Plate Method - 35 ± 0.5°C/48 ± 3 h - Plate count agar (Standard Methods, 1985).

the supernatant analysed for unsorbed aluminium, using the Eriochrome cyanine-R method (Standard Methods, 1985). Employing the optimum time of agitation (sorption time) from the kinetic tests, equilibrium sorption tests were conducted with four alum concentrations (0.025, 0.050, 0.075 and 0.100 M) to estimate the optimum concentration of alum solution for alum treatment. All sorption tests were performed in triplicate.

4.2.2 Silver Incorporation

Silver incorporation was carried out using two methods. In the first method, 5 g alum treated Giridih bituminous

coal, prepared employing the standardised procedure (4.2.1), was brought in contact with 100 ml silver nitrate solution (0.5 mg Ag/L). In the second method, 5 g raw Giridih bituminous coal was brought in contact with a 100 ml mixed solution of silver nitrate (0.5 mg Ag/L) and alum (concentration as estimated in 4.2.1). In both, the contents were agitated in an end-over-end shaker at the rate of 20 rpm for different contact times (1, 6 and 24 h). At the end of the desired contact times, the silver incorporated alum treated Giridih bituminous coal media were separated from the solution, washed with distilled water and dried overnight at 103°C.

To estimate silver incorporation using these contact times, silver incorporated media (5 percent) was refluxed in 40 ml 0.1N nitric acid for 20 min (Sarkar, 1987). Following cooling, the contents were filtered (0.45 μm membrane filter) and the filtrate analysed for silver, using a silver ion electrode (Model 94-16, Orion Research Inc., Cambridge, MA, U.S.A.).

4.2.3 Column Studies

A simple bench-scale set up was employed to test the prepared media in terms of their capacity to remove bacteria and turbidity from surface as well as ground water under condition similar to that would be encountered in a domestic water filter. Column studies were carried out using a 10 cm media depth (unless otherwise mentioned) in a 30 cm x 2.5 cm ID perspex column at the rate of 0.27 m/h which corresponded to a bed contact time of 10 min. The column effluents were monitored for pH,

turbidity and bacteria (faecal coliform - membrane filter (MF) method - 44 $\pm$ 0.5°C/24 h - MFC broth (WHO, 1985) or total coliform - pour plate method - 37 $\pm$ 0.5°C/48 $\pm$ 3 h - McConkey agar (McCambridge and McMeekin, 1979), and heterotrophic plate count - pour plate method - 35 $\pm$ 0.5°C/48 $\pm$ 3 h - plate count agar (Standard Methods, 1985)) at selected time intervals.

5. RESULTS AND DISCUSSION

In view of the objective of the study, the experimental work was carried out in two phases, viz., standardisation of the method of preparation of silver incorporated alum treated bituminous coal media and column studies to test the performance of the prepared media in removing bacteria and turbidity from surface as well as ground water samples. All experiments for standardisation of the method of media preparation were performed in triplicate and the data reported in figures and tables represent the mean values. All bacterial enumeration were made in duplicate and the mean values are reported.

5.1 Batch Sorption Kinetic Tests

Raw Giridih bituminous coal was subjected to batch sorption kinetic tests using three alum concentrations (0.025, 0.050 and 0.075 M). The objective of this test was to estimate the agitation time required for bulk sorption of aluminium. The results indicate that bulk of the sorption occurred in one h and a saturation was reached in 6 h (Figure 1). Subsequently, 6 h agitation time for alum treatment was employed.

5.2 Batch Equilibrium Sorption Tests

Equilibrium sorption tests (sorption time 6 h) were conducted with four alum concentrations (0.025, 0.050, 0.075 and 0.100 M) to estimate the concentration of alum solution for alum treatment of Giridih bituminous coal. Figure 2 presents data on the amount of aluminium sorbed vs. molarity of alum solution. It is observed that maximum aluminium sorption corresponded to 0.075 M

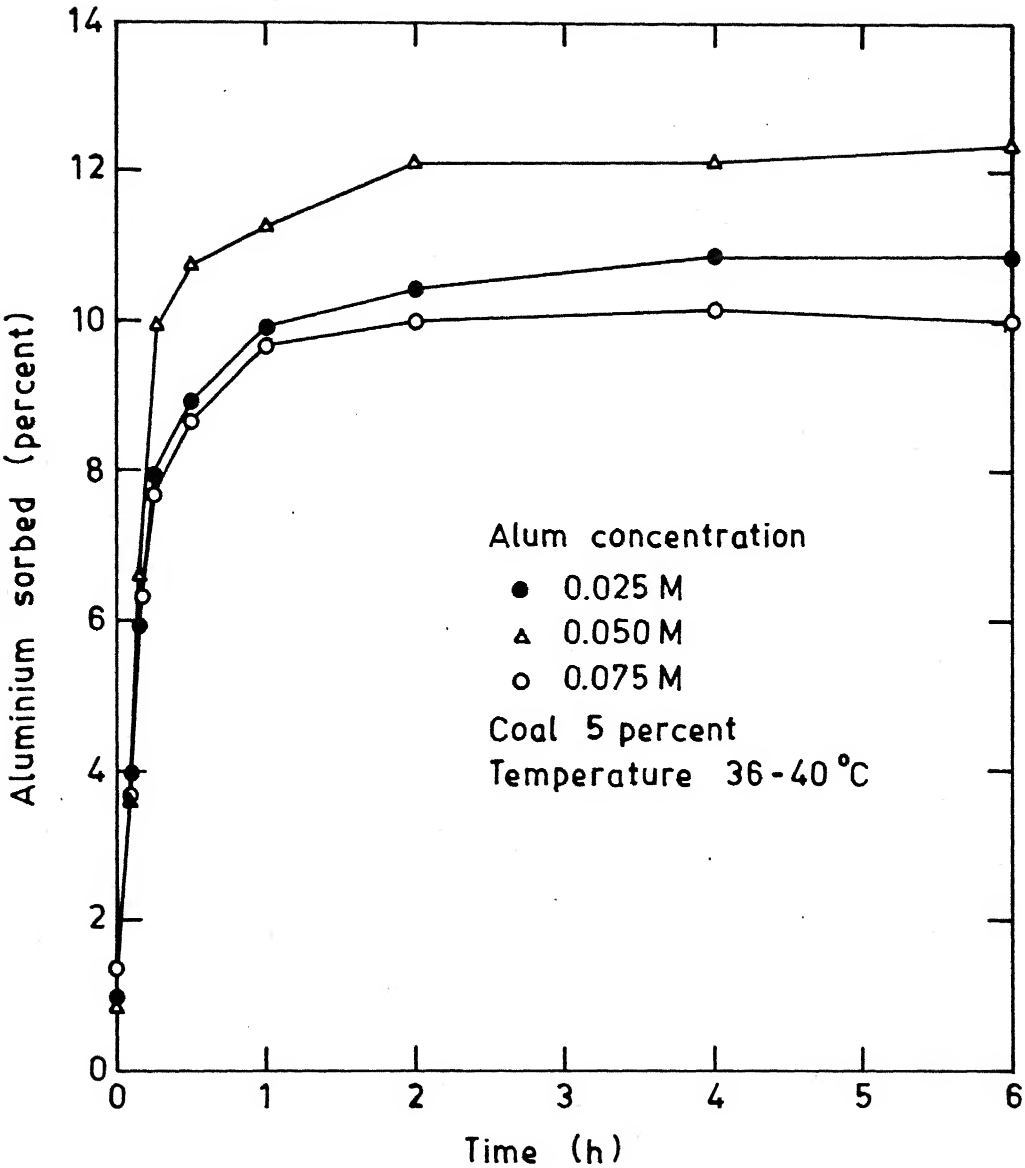

Fig. 1. Aluminium — Giridih bituminous coal sorption kinetics.

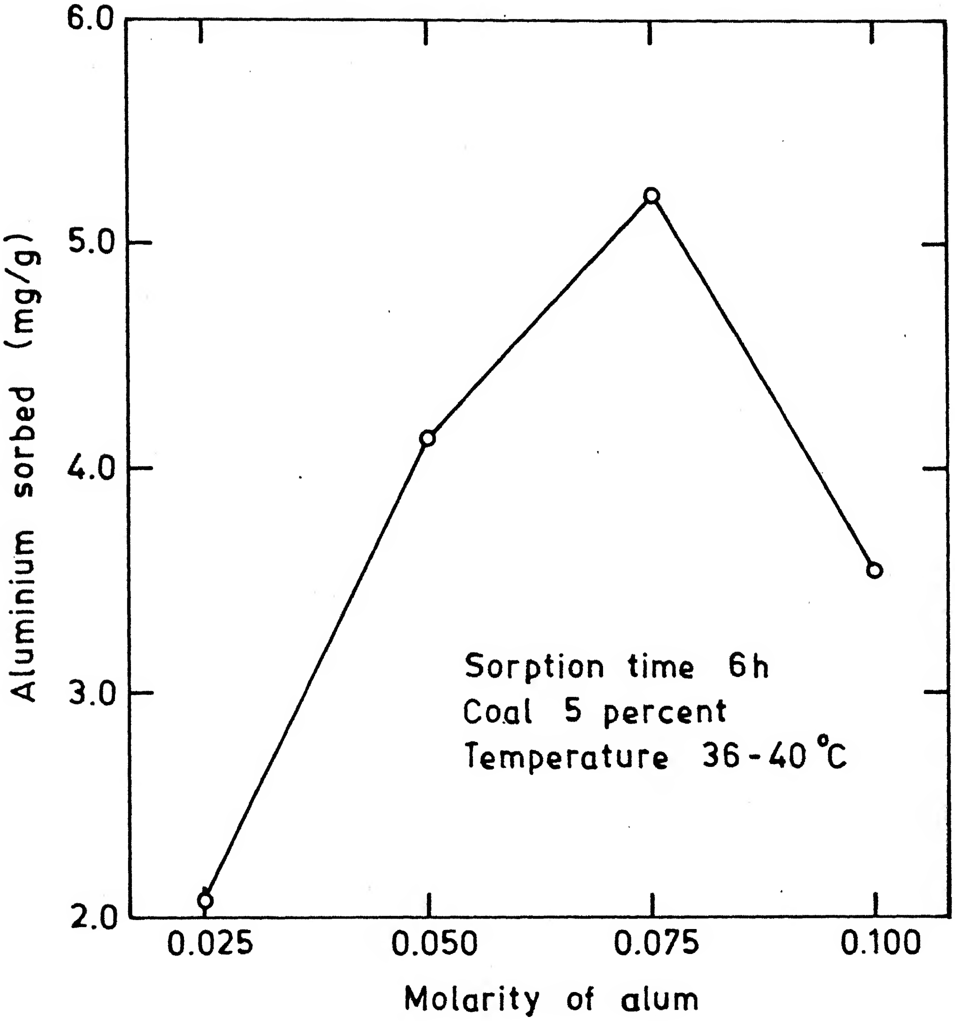

Fig. 2. Aluminium — Giridih bituminous coal equilibrium sorption.

alum solution. Decreased aluminium sorption for 0.100 M alum solution is probably due to association of the solute in solution, i.e., with increase in solute concentration, the solute-solute attraction begins to increase more rapidly than the substrate (media)-solute attraction (Giles, 1970). Subsequently, 0.075 M alum solution was employed for alum treatment.

5.3 Silver Incorporation

Silver incorporation using different contact times (1, 6 and 24 h) was carried out by two methods, viz., silver incorporation following alum treatment and silver incorporation along with alum treatment. The two media were designated as Alum-GBC-Ag and Alum/Ag-GBC, respectively. Keeping in view the difficulty that would be encountered in preparation of silver incorporated media employing a natural water with its background chloride concentration, silver incorporation was carried out employing a 0.5 mg Ag/L silver nitrate solution which corresponds to within the solubility of silver in presence of chloride. To estimate the time for maximum silver incorporation, the two media (prepared using three different contact times) were subjected to refluxing in 0.1N nitric acid and the refluxing solution filtrates were analysed for silver. According to the data presented in Table 3, a 6 h silver incorporation time for Alum-GBC-Ag and a 6 h alum/silver treatment/incorporation time for Alum/Ag-GBC respectively, showed maximum silver in refluxing solution filtrate.

5.4 Standard Methods of Media Preparation

Based on the data presented in the preceding sections, the

Table 3. Silver in Silver Incorporated Media

Media	Ag incorporation or alum/Ag treatment/ incorporation time (h)	Silver in refluxing solution filtrate (μg Ag/g)			
		Test 1	Test 2	Test 3	Mean
Alum-GBC-Ag	1	4.13	3.71	6.56	4.80
	6	7.19	5.77	7.72	6.89
	24	6.75	4.14	6.32	5.74
Alum/Ag-GBC	1	5.17	3.48	5.00	4.55
	6	6.45	4.18	7.02	5.88
	24	5.18	3.36	4.03	4.19

Note: Alum treatment time for Alum-GBC-Ag 6 h; silver was not detected in refluxing solution filtrate of raw GBC.

following methods of preparation were employed for Alum-GBC-Ag and Alum/Ag-GBC:

a. Alum-GBC-Ag. 6 h agitation of 10 g GBC in 200 mL 0.075 M alum solution; overnight drying at 103°C; 6 h agitation of 10 g alum treated GBC in 200 mL 0.5 mg Ag/L silver nitrate solution; overnight drying at 103°C.

b. Alum/Ag-GBC. 6 h agitation of 10 g GBC in 200 mL 0.075 M alum and 0.5 mg Ag/L silver nitrate solution; overnight drying at 103°C.

5.5 Column Studies

To test the performance of the prepared media in removing bacteria and turbidity from water, column studies were conducted with Alum-GBC-Ag and Alum/Ag-GBC. Ganga water as well as a well water with their natural bacterial population and turbidity were used in the study. A flow rate of 0.27 m/h was employed which corresponded to a bed contact time of 10 min. The column effluent was monitored for pH, turbidity and bacteria (faecal coliform – membrane filter (MF) method – 44 $\pm$ 0.5°C/24 h – MFC broth (WHO, 1985) or total coliform – pour plate method – 37 $\pm$ 0.5°C/48 $\pm$ 3 h – McConkey agar (McCambridge and McMeekin, 1979); heterotrophic plate count – pour plate method – 35 $\pm$ 0.5°C/ 48 $\pm$ 3 h – plate count agar (Standard Methods, 1985)) at selected time intervals.

Performance of the two media, viz., Alum-GBC-Ag and Alum/Ag-GBC in removing bacteria and turbidity from the Ganga water are shown in Figures 3(a) and 3(b). Variation of effluent turbidity and pH is also shown. Alum-GBC-Ag showed better

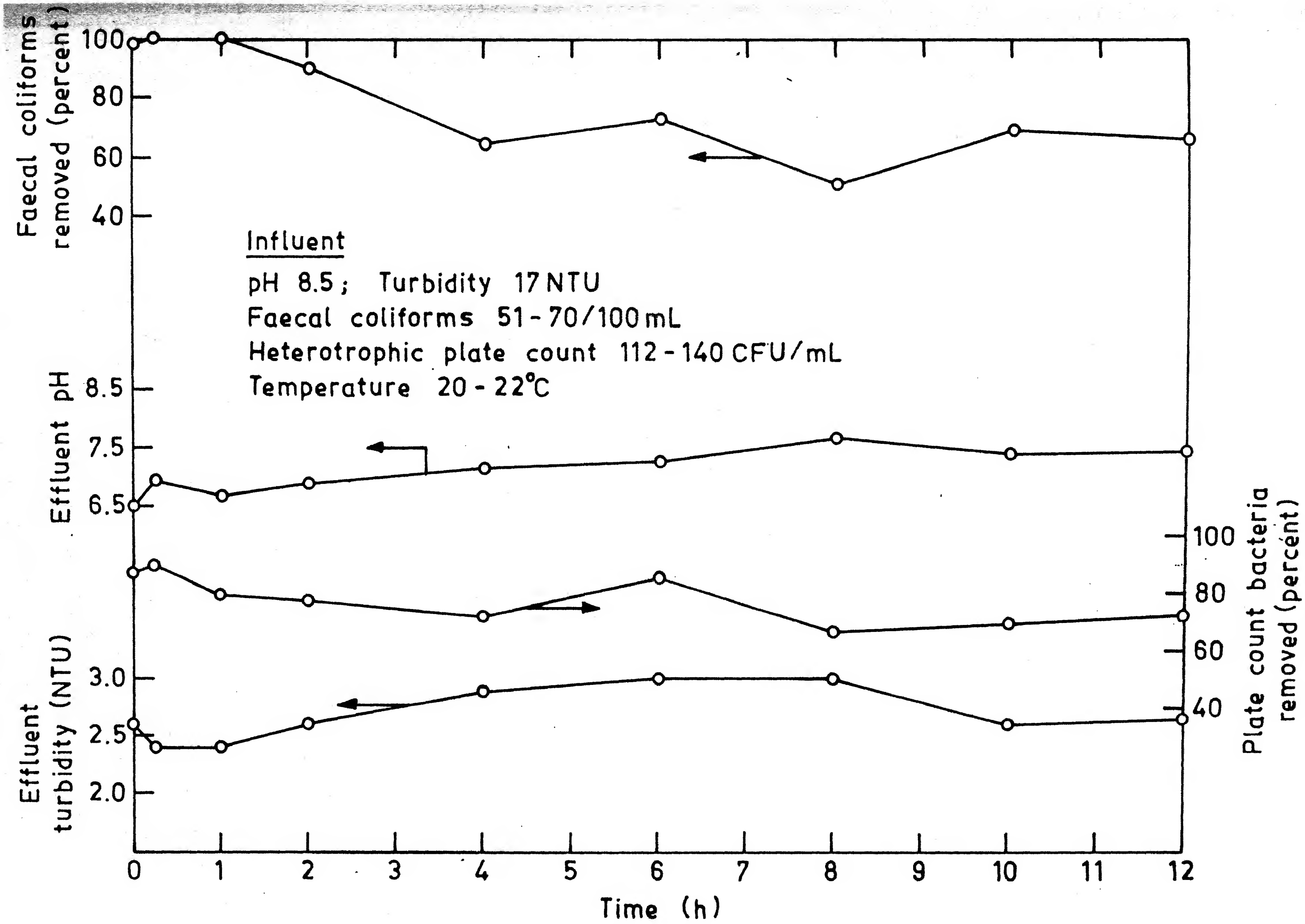

Fig. 3(a). Alum/Ag-GBC — Ganga water column study.

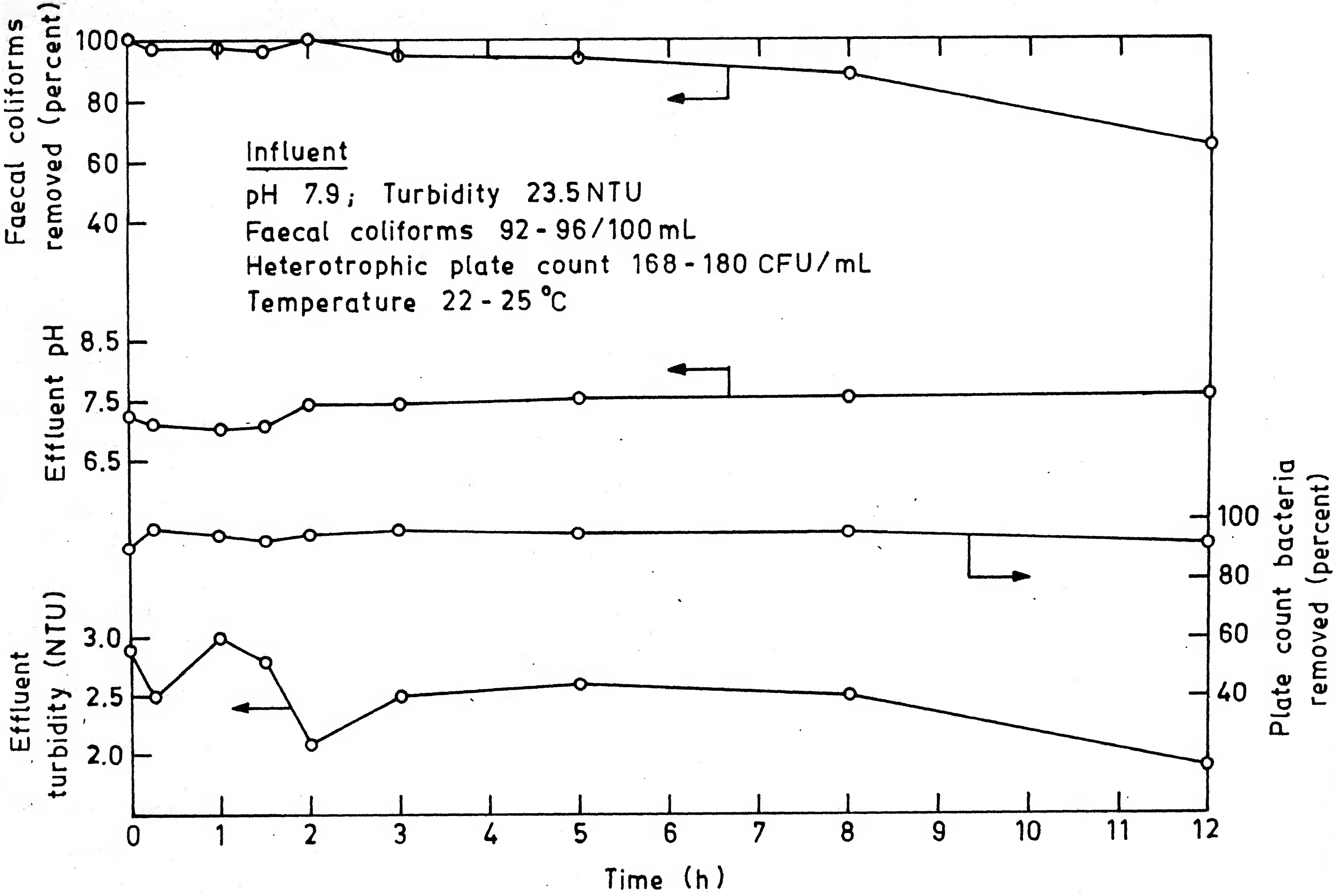

Fig. 3(b). Alum-GBC-Ag — Ganga water column study.

performance — higher faecal coliform removal (about 90 percent) as well as heterotrophic plate count bacteria removal (about 92 percent) upto 8 h. Turbidity removal was also comparatively more. Lower removal of bacteria by Alum/Ag-GBC was presumably due to lower silver incorporation (Table 3).

Further, Alum-GBC-Ag was subjected to a column study, using 5 cm bed depth, to compare its performance with the results obtained by Jayadev (1987). From Figure 4, it is observed that even after 5 h, total coliform removal was 95 percent and heterotrophic plate count bacteria removal was 84 percent; at 8 h, total coliform removal decreased to 82 percent and heterotrophic plate count bacteria removal remained same. Alum-GBC-Ag prepared by Jayadev performed well upto 4 h (96 percent total coliform removal and 82 percent plate count bacteria removal) and its performance deteriorated thereafter (Jayadev, 1987). Jayadev used 1 M alum solution for alum treatment and 24 h silver incorporation time. Data obtained in the present study (Figure 2 and Table 3) indicate presumably lower alum as well as silver incorporation in Alum-GBC-Ag prepared by Jayadev. Improved performance of Alum-GBC-Ag prepared in the present study may be attributed to higher alum as well as silver incorporation. The column study (Figure 4) also indicated potential of the prepared media for long duration column operation.

Alum-GBC-Ag — well water column study was carried out to investigate the performance of the media in removing bacteria from ground water (Figure 5). High removals of total coliform

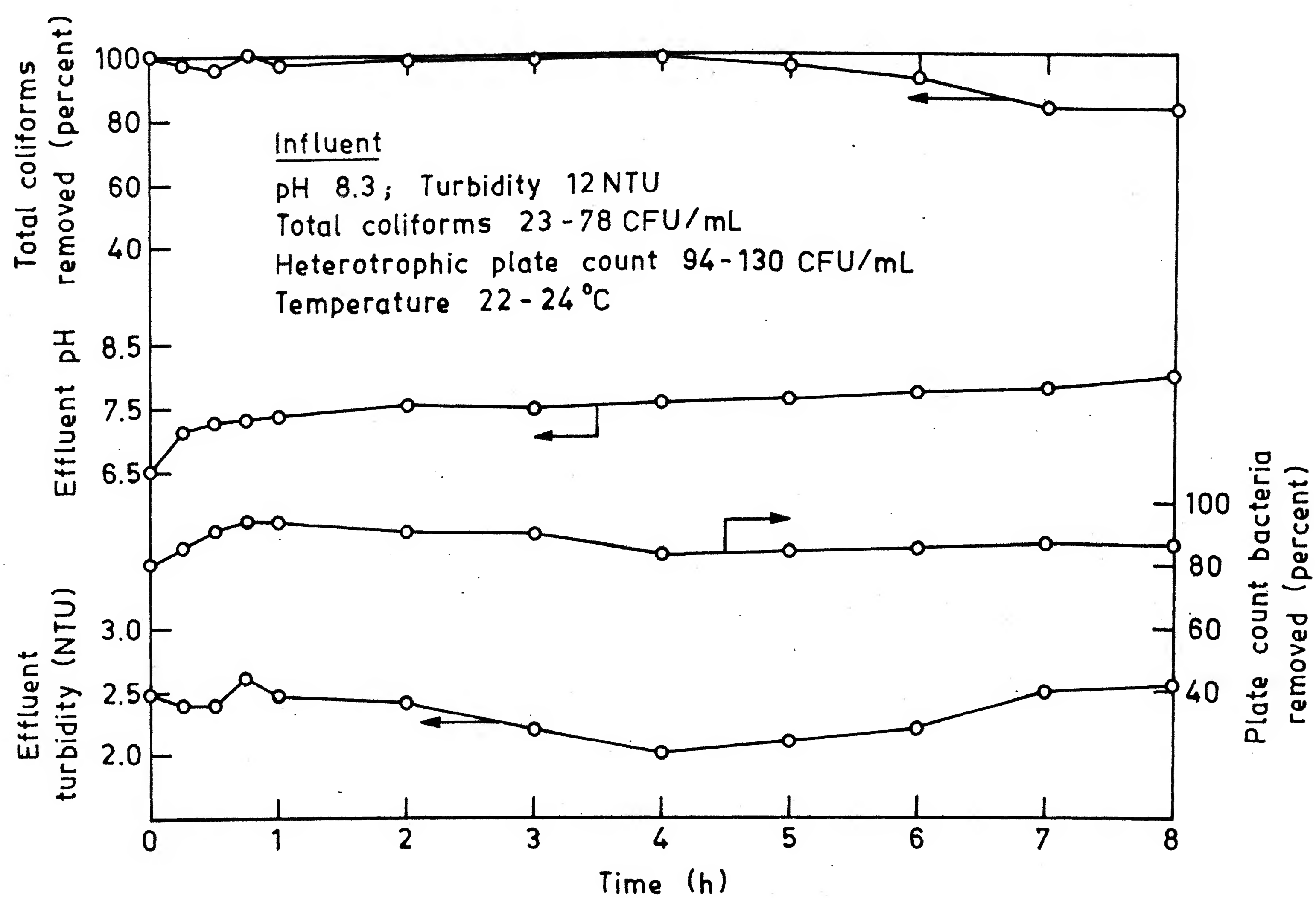

Fig. 4. Alum-GBC-Ag — Ganga water column study (5 cm bed depth)

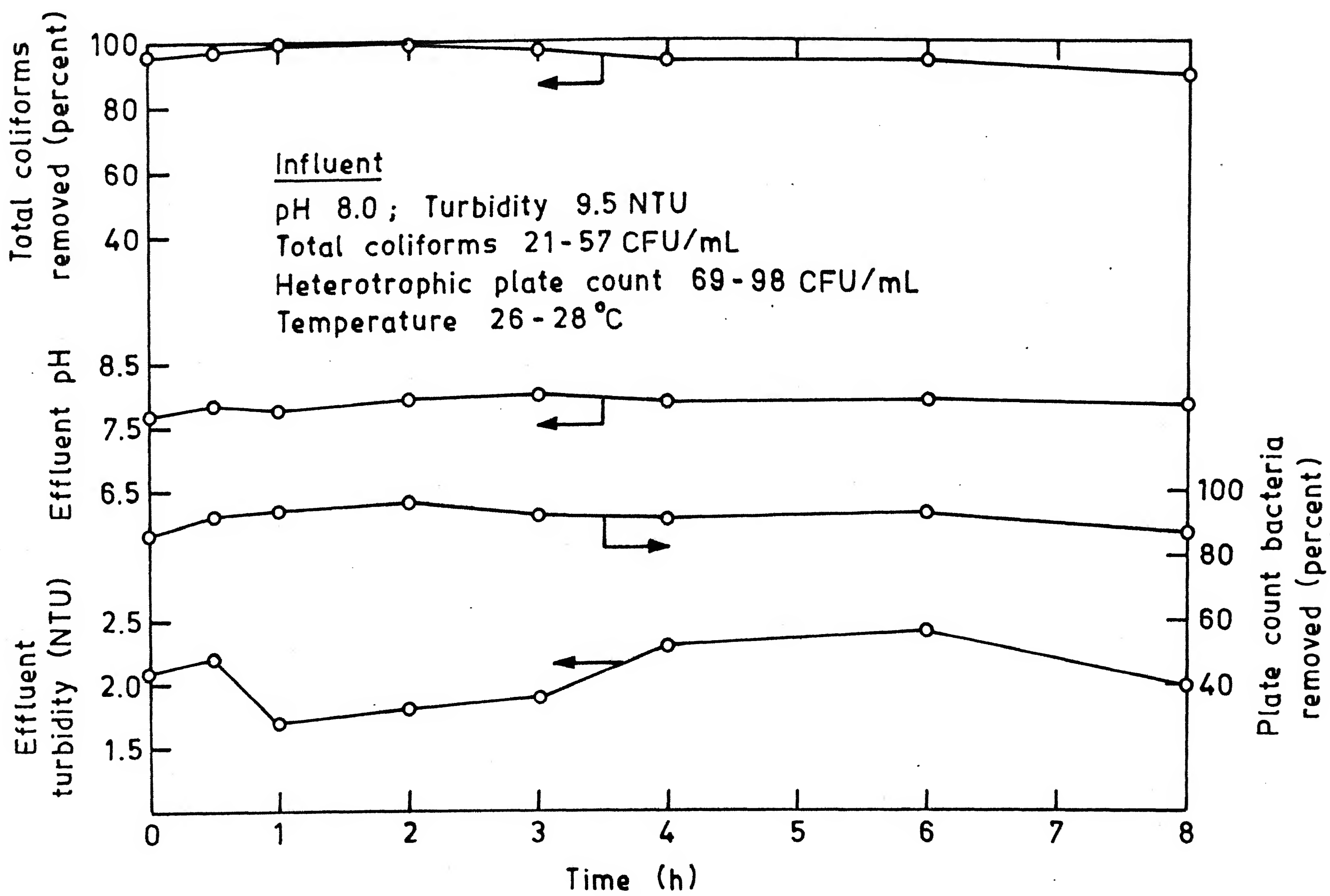

Fig. 5. Alum-GBC-Ag — well water column study.

(90 percent) and heterotrophic plate count bacteria (88 percent) were observed during a 8 h filter run.

Column studies (4 and 8 d) were performed to demonstrate the bacterial removal capacity of Alum-GBC-Ag in long duration column operation. The effluent characteristics (faecal coliform and heterotrophic plate count bacteria, pH and turbidity) are shown in Figure 6. Leakage of faecal coliform observed during the first day in both runs cannot be readily explained. Nevertheless, low faecal coliform levels (0-3/100 mL) were observed in the effluent in both runs following $1\frac{1}{2}$ d and continued upto 4-8 d. Increase in effluent heterotrophic plate count bacteria after 4 d (Run 2) indicated probable exhaustion of the media; however, this was not reflected in effluent faecal coliform presumably due to lower viable coliforms in the influent. Effluent turbidity levels in both runs remained below 3 NTU and effluent pH in the range 7-8.

Based on the results of the column studies, it may be stated that standardisation of the method of preparation of silver incorporated alum treated bituminous coal media is a significant advancement in the direction of development of filtration/adsorption media for removal of bacteria and turbidity from water. The media showed high removal of faecal coliform, total coliform and heterotrophic plate count bacteria. Effluent turbidity levels were always below 5 NTU. According to Faechem (1980), it may not always be required to achieve 'zero faecal coliform' in a rural water supply which is not chlorinated and any device which can reduce substantial number of coliforms

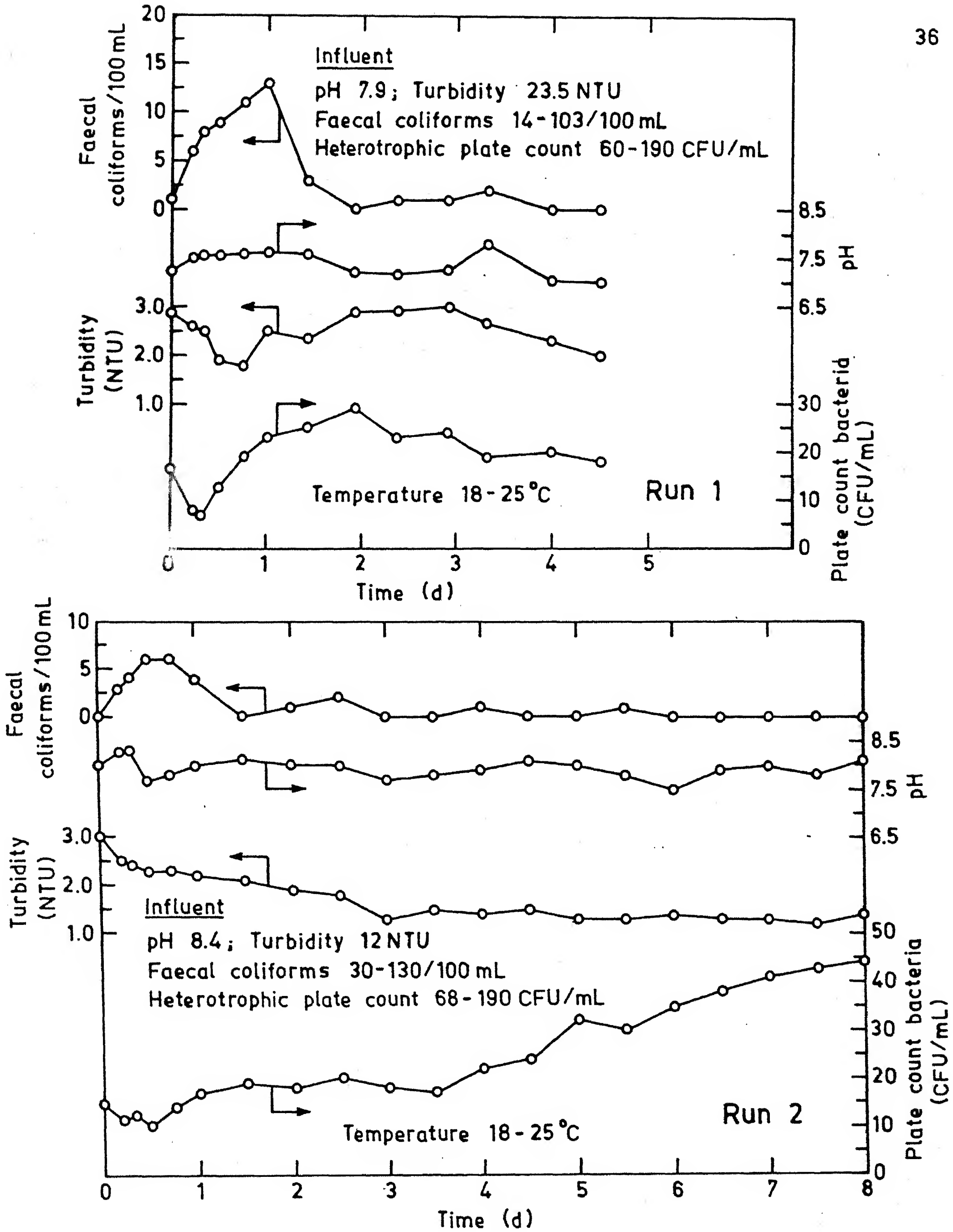

Fig. 6. Effluent characteristics of Alum-GBC-Ag — Ganga water long duration column study.

from drinking water will be a step in the direction of achieving the ultimate goal of 'no faecal coliform' in the drinking water.

6. SUMMARY AND SUGGESTIONS FOR FUTURE WORK

In the present study, standardisation of the method of preparation of silver incorporated alum treated bituminous coal media was carried out and the performance of the prepared media in removing bacteria and turbidity from water was tested in column studies, employing surface as well as ground water samples. From batch sorption kinetic tests, 6 h agitation time was found to be optimum for alum treatment and 0.075 M alum solution was selected from batch equilibrium sorption tests for alum treatment. Six h contact time showed maximum silver incorporation. In column studies, Alum-GBC-Ag (silver incorporation following alum treatment) showed better performance than Alum/Ag-GBC (silver incorporation along with alum treatment). It also showed improved performance in comparison to the media prepared by Jayadev (1987). High removal of bacteria was also observed in Alum-GBC-Ag – well water column study. Effluent characteristics of long duration (4-8 d) column studies demonstrated the potential of Alum-GBC-Ag as a media for domestic water filters in the rural areas of the developing countries. Based on the results of the present study, it may be stated that standardisation of the method of preparation of silver incorporated alum treated bituminous coal media is a significant advancement in the direction of filtration/adsorption media for removal of bacteria and turbidity from water.

It is felt that further long duration column studies, employing larger diameter columns (5-10 cm) and simulating the

intermittent use pattern of domestic water filters, should be carried out with raw water (surface and ground) samples of varying characteristics. Reuse of the spent media should also be investigated. Extensive studies should also be undertaken to compare the media with commercially available domestic water filters in terms of both efficiency and cost.

REFERENCES

Bhattacharya, A.K. and Venkobachar, C. (1984). Removal of cadmium(II) by low cost adsorbents. Jour. Environmental Engineering Division, ASCE, 110, 110.

Chaudhuri, M. and Sattar, S.A. (1986). Enteric virus removal from water by coal-based sorbents: Development of low-cost water filters. Presented at 13th IAWPRC Biennial International Conference on Water Pollution Research and Control, Rio de Janeiro, Brazil.

Chaudhuri, M. and Sattar, S.A. (1988). Removal of human rotavirus from water by coal-based sorbents. Accepted for presentation at the First Biennial Water Quality Symposium: Microbiological Aspects, Banff, Alberta, Canada.

Dhage, S.S., Joshi, N.S. and Paramasivam, R. (1986). Quality of rural water supply in four states of India. Jour. Indian Water Works Association, 18, 27.

Feachem, R. (1980). Bacterial standards for drinking water quality in developing countries. The Lancet, Aug. 2, p. 255.

Geldreich, E.E. (1976). Faecal coliform and faecal streptococus density relationships in waste discharges and receiving waters. CRC Critical Reviews in Environmental Control, 6, 349.

Giles, C.H. (1970). Interpretation and use of sorption isotherms. In Sorption and transport processes in soils, (Gregory, J.G., ed.). Monograph No. 37, Society of Chemical Industries, London, p. 14.

Govt. of India (1981). Sixth five year plan 1980-85. Planning Commission, Govt. of India, New Delhi, India.

Govt. of India (1983). Sixth five year plan - Mid term appraisal. Planning Commission, Govt. of India, New Delhi, India.

Govt. of India (1984). The approach to the seventh five year plan 1985-90. Planning Commission, Govt. of India, New Delhi, India.

Jayadev, S. (1987). Silver incorporated filtration/adsorption media for removal of bacteria from water. M.Tech. thesis, Dept. of Civil Engg., Indian Institute of Technology, Kanpur, India.

Jayasimha, B.N. (1983). Sorption of humic acid in water on hydrous Fe/Mn oxides impregnated coal. M.Tech. thesis, Dept. of Civil Engg., Indian Institute of Technology, Kanpur, India.

Karthikeyan, J. (1982). Enhancement of mercury(II) removal by coal through chemical pretreatment. M.Tech. thesis, Dept. of Civil Engg., Indian Institute of Technology, Kanpur, India.

Kiran Kumar, T.V. (1984). Sorption of mercury(II) on coal impregnated with oxides of manganese. M.Tech. thesis, Dept. of Civil Engg., Indian Institute of Technology, Kanpur, India.

Kulkarni, D.N., Tajne, D.S. and Parhad, N.M. (1980). Performance of domestic water filters. Indian Jour. Environmental Health, 22, 30.

Lee, E.W. (1984). Asian Environment, 6, 4.

Mahnel, H. and Schimidt, M. (1986). Uber die wirkung von silberverbindungen auf viren in wasser. Zentralblatt fur Bakteriologie Mikrobiologie und Hygiene, 182, 381.

McCambridge, J. and McMeekin, T.A. (1979). Protozoan predation of Escherichia coli in estuarine waters. Water Research, 13, 659.

Oza, P.P. and Chaudhuri, M. (1975). Removal of viruses from water by sorption on coal. Water Research, 9, 707.

Oza, P.P. and Chaudhuri, M. (1976). Virus-coal sorption interaction. Jour. Environmental Engineering Division, ASCE, 102, 1255.

Oza, P.P. and Chaudhuri, M. (1977). Some notes on virus sorption on coal. Jour. General Applied Microbiology, 23, 1.

Pandey, M.P. and Chaudhuri, M. (1981). Inorganic mercury bituminous coal sorption interaction in water. Water Science and Technology, 13, 697.

Pandey, M.P. and Chaudhuri, M. (1982). Removal of inorganic mercury from water by bituminous coal. Water Research, 16, 1113.

Prasad, V.S. (1986). Development of filtration/adsorption media for removal of bacteria and turbidity from water. Ph.D. thesis, Dept. of Civil Engg., Indian Institute of Technology, Kanpur, India.

Richard, L.W. (1963). Review of the bactericidal effectiveness of silver. Jour. Americal Water Works Association, 55, 881.

Smith, D.K., Thomas, G.H., Christison, J. and Chatfield, E. (1977). Survey and test protocols for point-of-use water

purifiers. Environmental Health Directorate, Health Protection Branch, Department of National Health and Welfare, Ottawa, Canada.

Sriramulu, N. and Chaudhuri, M. (1976). Dual-media coal-sand filtration and its virus removal potential. Indian Jour. Environmental Health, 18, 77.

Standard methods for the examination of water and wastewater, Sixteenth edition (1985). American Public Health Association, Washington, D.C., U.S.A.

Sarkar, S. (1987). Personal communication.

The Statesman, New Delhi (1988). Jan. 23.

Water Front (1982). UNICEF, New York, U.S.A., No. 29.

WHO (1984a). International drinking water supply and sanitation decade - Review of national baseline data. WHO offset publication No. 85, World Health Organisation, Geneva.

WHO (1984b). Guidelines for drinking water quality. Vol. 1. Recommendations. World Health Organisation, Geneva.

WHO (1984c). Guidelines for drinking water quality. Vol. 2. Health criteria and other supporting information. World Health Organisation, Geneva.

WHO (1985). Guidelines for drinking water quality. Vol. 3. Drinking-water quality control in small-community supplies. World Health Organisation, Geneva.